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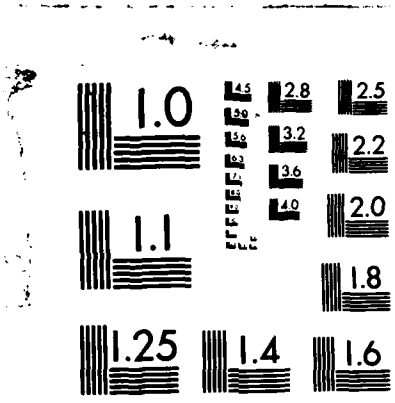

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This experiment examined the effect of the amount of single-task practice on the performance of two task combinations. Wickens' Multiple Resources Model was used to construct the combinations. According to this model, one of the combinations (the shared resources combination) was composed of two tasks requiring the same information processing resources. The other combination, (the separate resources combination) was composed of two tasks requiring different resources. Three groups of 12 subjects performed each combination. Groups 1, 2, and 3 performed the shared resources combination; Groups 4, 5, and 6 performed the separate resources combination. Pretest data were used to determine the number of trials required to approach data were used to determine the number of trials required to approach asymptotic performance on each of the four tasks used in the two combinations.

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Groups 3 and 6 received enough trials on their tasks to approach asymptotic performance. Group 2 received half the practice of Group 3 on each task; Group 5 received half the practice of Group 6. Groups 1 and 4 received one trial on each task. Analyses of the dual-task data appeared to indicate that the amount of single-task practice had little effect on either combination. However, an examination of the single-task data revealed that Groups 2 and 3 performed similarly on both their tasks. Group 5 and 6 performed similarly on one of their tasks. The single-task practice manipulation was, therefore, unsuccessful since it had little effect on single-task performance. Consequently no conclusions can be drawn from this experiment about the effect of the amount of single-task practice on dual-task performance.

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Introduction

There are many unresolved questions about multiple-task performance. One of the most basic questions concerns the relation between the amount of single-task practice and subsequent dual-task performance. At first glance, it seems obvious that dual-task performance should improve as the amount of single-task practice on each of the tasks comprising the combination (component tasks) increases. However, after some reflection it becomes apparent that the relation between the amount of single-task practice on each of the component tasks and dual-task performance may not be so straightforward. If, for example, a given task combination requires a great deal of timesharing skill for adequate dual-task performance, increasing the amount of practice on each of the component tasks beyond some minimal amount may have little or no effect on subsequent dual-task performance. If, on the other hand, the combination requires little timesharing skill, the amount of single-task practice on each of the component tasks may have a direct relation to the subsequent dual-task performance.

Surprisingly, there has been little attempt to determine the relation between dual-task performance and the amount of single-task practice on the component tasks (see Folds, Gerth, & Engelman, in press, for a notable exception); and until recently, there has been no way to predict, even in a very general sense, the relation between the amount of single-task practice and dual-task performance. However, Wickens' Multiple Resources Model (Wickens & Sandry, 1982) may provide a theoretical framework for establishing this relation. This model proposes that human information processing capacity is composed of a number of specific resources rather than one undifferentiated capacity. Although specific resources have not yet been exhaustively identified, Sandry and Wickens (1982) have argued that some resources are defined along three dichotomous dimensions: 1) stage of processing (perceptual/central versus response selection/execution), 2) stimulus modality , and 3) central processing code (verbal versus spatial). Response mode (speech versus manual) is assumed to be highly correlated with code of processing. That is, under some conditions the speech response resource may be thought of as part of the verbal central processing resource but may act as a separate resource under other conditions. Similarly, the manual response resource may be considered as part of the spatial processing resource on some occasions and as a separate resource on others. For the purposes of this paper, the response resources will be assumed to be separate from the central processing resources.

Wickens' Model implies that dual-task performance should deteriorate as the number of resources shared by two tasks increases. The results of Tsang and Wickens (1983) strongly support this implication. Additionally, some of their data indicate that resource allocation skills (as reflected in

deviations from specified performance levels in changing difficulty conditions) improve as the number of shared resources increases. These results suggest that as the number of shared resources increases, resource allocation skills should become increasingly important in determining dual-task performance. Consequently, dual-task performance should be less influenced by the amount of single-task practice. In contrast, if two tasks require completely different resources, then resource allocation skills should have little effect on dual-task performance and the amount of single-task practice on each of the component tasks should have a direct relation to dual-task performance.

It is assumed that other timesharing skills, such as parallel information processing and rapid intertask switching, have the same relation to the number of shared resources as resource management skills: As the number of shared resources increases, timesharing skills exert more influence on dual-task performance. No attempt will be made, however, in the experiment described below to measure parallel processing or intertask switching skills directly. Instead, each subject's response strategy will be identified. These strategies reflect the presence of parallel processing and rapid switching skills (Damos & Wickens, 1980; Damos, Smist, & Bittner, 1983) although they provide no estimate of the amount of parallel processing or the rate of intertask switching.

Two task combinations were constructed for the experiment described below. The tasks of the first combination, the shared resources combination, used the same stimulus modalities, the same response modalities, and the same central processing code (verbal). Thus, the amount of single-task practice received on each of the component tasks should have little relation to subsequent dual-task performance. The tasks of the second combination, the separate resources combination, used different stimulus modalities, different response modalities, and different central processing modes (spatial and verbal). Thus, practice on the component tasks of this combination should be directly related to subsequent dual-task performance. Wickens' S-C-R compatibility principle (Wickens, Sandry, & Vidulich, 1983) was used to determine the relation between the stimulus modality, the central processing code, and the response modality to insure optimal dual-task performance for this combination.

Method

Subjects

A total of 72 subjects completed the experiment. All were right-handed females between the ages of 18 and 35. Subjects were recruited through advertisements placed in university buildings and in the student newspaper. All subjects were paid $5.00/hour.

Apparatus

The main system for this experiment consisted of a DEC 11/23 computer. All visual inputs to the subject were displayed on an Amdek Model Video 300 CRT. All auditory inputs to the subject were presented using a Telex CS-61 headphone/microphone set. The subject responded using two identical 4 by 4 matrix-type keyboards or the headphone/microphone set. The subject was seated 107 cm from the CRT. A Digitalker voice-synthesis speech-processor board generated the auditory stimuli and a Votan V5000--a speaker-dependent, isolated-word recognition system--recorded the subject's vocal responses.

The amplifier sensitivity (gain) level and rejection (a rejection occurred when the speech recognition unit failed to recognize the response) levels of the Votan V5000 were set to the default values of the system (Level 4 and Level 1, respectively), since pretesting showed these to be the most reliable. These levels resulted in an average single-task rejection rate of 4.3% and a dual-task rejection rate of 2.0%. The noise level in the testing room was approximately 52 dB(a).

Tasks

Matrix. For this task 5 by 5 matrix grids measuring 8 cm by 8 cm were presented sequentially to the subject. Each matrix had

five illuminated cells that were selected at random. The subject's task was to determine if the current matrix was identical to the preceding matrix rotated 90 degrees to the right or left. Each time a response was made, another matrix was presented. If the current matrix was a rotated version of the preceding matrix, the subject responded "same" by pressing a key under her left index finger. If the current matrix was different, the subject responded "different" by pressing a key under her left middle finger. The response to the first matrix pattern of any block was always "same." For every block approximately 50% of the correct responses were "same" and 50% , "different." The same matrix could be shown sequentially (in its rotated form) a maximum of four times. The stimulus was displayed until the subject made a response at which time it was erased and a new stimulus presented within 33 ms.

Two dependent variables were calculated for each block: the correct response time (correct RT) and the percentage of correct responses. At the end of each single- and dual-task block, the percentage of correct responses and the correct RT were displayed to the subject. The correct RT used for feedback was calculated by dividing 60 by the number of correct responses for the block. The true correct RT was used for the analyses.

Alphabet. Randomly selected letters of the alphabet were presented sequentially on the CRT. The subject determined the alphabetical order of the letter currently displayed and the letter that had just been displayed. If the current letter preceded the most recently displayed letter in the alphabet, the subject pushed a key under her left middle finger. If the current letter followed the most recently displayed letter in the alphabet, the subject pushed a key under her left index finger. As soon as the subject made a response, the current letter was erased and a new one presented. The first response on any trial to this task was always counted as correct. The same dependent measures were calculated as above.

Running difference. In this task randomly selected digits between zero and eight were presented sequentially to the subject. The subject responded with the absolute difference between the most recently displayed digit and the preceding digit. The possible responses consisted of the numbers one through eight. All nine digits were presented with approximately the same frequency and a digit was never allowed to repeat. The response to the first stimulus of any block was always "1." As soon as a response was made, a new stimulus was presented.

Two versions of this task were used. In one version the stimuli were presented visually and the subject responded manually by pressing one of eight keys on her right-hand keypad. In the other version stimuli were presented auditorily through the headphones and the subject responded vocally using the Votan V5000. Visual digits were 2.5 cm high; auditory digits were presented at 78 dB(a). Both the auditory and visual stimulus

duration was 343 ms and could be terminated by a response before the end of the presentation interval.

All responses were measured from the onset of the stimulus regardless of modality. Vocal response times were measured to the end of the recognition period, which required approximately 300 to 350 ms. As in the two preceding tasks, correct RT and percentage of correct responses were calculated as dependent measures. Rejections were treated as correct answers for calculating these two variables. Words incorrectly recognized by the Votan V5000 were not recorded because pretest data indicated that less than 1% of the responses were misrecognized. It was assumed that this misrecognition rate would have a negligible effect on any statistical analyses.

The visual-manual version of this task was performed with the alphabet task under dual-task conditions. The auditory-speech version was performed with the matrix task. In both combinations the tasks were completely independent of each other. Both dependent variables were calculated the same way under single- and dual-task conditions and the same feedback was given for each task.

Design

A three-factor, mixed-model design was used. Resource overlap (separate versus shared) was a between-subjects factor. The amount of single-task practice received on each component task also was a between-subjects factor with three levels determined from pretest data. These three levels were 1) the number of 1-min trials required to approach asymptotic performance 2) 50% of the number of trials required to approach asymptotic performance 3) one trial. The amount of single-task practice will be referred to as the "group" factor to prevent confusion with the third experimental factor, dual-task trials, a within-subject factor.

Procedure

When the subject arrived, she was asked to read and sign an informed consent form. She was then assigned randomly to one of six experimental groups. Groups 1, 2, and 3 (the shared

resources groups) performed the alphabet task and the visual-manual version of the running difference task. Groups 4, 5, and 6 (the separate resources groups) performed the matrix task and the auditory-speech version of the running difference task. Groups 1 and 4 received one trial on each of their respective tasks before performing the tasks concurrently. Group 2 received six trials on the alphabet task and eight trials on the running difference task. Group 5 received ten trials on the matrix task and eight on the running difference task. Group 3 received 12 trials on the alphabet task followed by 16 trials on the running difference task. Group 6 received 20 trials on the matrix task followed by 16 trials on the running difference task. Thus, Groups 2 and 5 received 50% of the trials required to approach asymptotic performance on each of their tasks; Groups 3 and 6 received the total number of trials necessary to reach asymptotic performance on their tasks. All groups practiced the left-hand task before the right-hand task.

Any subject in Groups 2, 3, 5, or 6 with less than 70% correct on the last five single-task trials of the running difference task was dropped from the experiment after the last single-task trial and paid accordingly. One subject in Group 5 and one in Group 6 were eliminated at this point in the study and replaced with new subjects.

All subjects received five blocks of five dual-task trials. There was a 5-min break between the second and third blocks and a 2-min break between the fourth and fifth blocks. All subjects except those in Groups 1 and 4 received a 2-min break before the first block of dual-task trials. After the subjects completed the last dual-task trial, they performed one trial on each task alone beginning with the running difference task. They then were debriefed and paid.

Before the subjects began the first dual-task trial, the three major response strategies used to perform discrete task combinations were explained. The subjects were told that they could respond simultaneously to the two task (simultaneous response strategy) or alternate their responses to the tasks (alternating response stragegy). The subjects also could make several responses to one task before responding to the other (massed response strategy) only if they made no more than four responses to one task before responding to the other. The subjects also were told that the tasks were equally important.

All single- and dual-task trials were 60 s long with a 60 s break between trials unless otherwise specified. The Votan 5000 was trained to each individual subject's voice in Groups 4, 5, and 6 (the speech response groups) before the experimental session. The training required the subject to repeat each possible response three times. During the experiment the number of rejections per trial was displayed on the experimenter's CRT. If the experimenter determined that too many rejections were occurring, the Votan V5000 was retrained. The unit was retrained

for two subjects in Group 6 and one subject in Group 5. Retraining occurred only during the predetermined rest periods, never during a block of trials. All instructions were taped and immediately preceded the first presentation of each task or combination.

Results

Only significant ($p < .05$) results are discussed below. Because of sphericity problems associated with repeated measures analyses, Huynh-Feldt adjusted F tests are reported unless otherwise indicated. The percentage correct data have been converted to percentage error (1-percentage correct) so that large scores represent poor performance for both the accuracy and the speed measures.

Single-Task Comparisons

To insure that there were no significant differences between the groups at the start of the experiment, a multivariate analysis of variance (MANOVA) was performed on the first trial of the running difference task for all six groups of subjects. No significant between-group difference was found. A similar analysis was conducted on the first trial of the alphabet task for the shared resources groups (Groups 1, 2, and 3) and on the first trial of the matrix task for the separate resources groups (Groups 4, 5, and 6). No significant between-group difference was found in either analysis.

These results should be treated with some caution because of possible problems with low statistical power. However, the data showed little evidence of consistent between-group performance differences. It seems reasonable, therefore, to assume that the groups did not differ significantly on single-task performance measures at the start of the experiment.

Dual-Task Analyses

Before performance on any task was analyzed, the correlation between the correct RT and the percentage error was calculated. If the correlation was significant, a MANOVA was performed on both the correct RT and percentage error. If the correlation was not significant, univariate analyses were performed on each measure separately.

Shared resources groups (Groups 1, 2, and 3). The percentage error and correct RTs were significantly correlated (r=.63,

$p<.001$) for the running difference task. A two-way (group by trial) MANOVA indicated only an effect of trial (Wilks' Lambda (48, 1582) =3.40, $p<.0001$). This effect was the result of the improvement in the percentage error (F (24, 792)=4.13, $p<.0001$) from 40.0% error on Trial 1 to 26.5% on Trial 25.

The percentage error and the correct RTs also were significantly correlated on the alphabet task ($r= .67$, $p<.001$). The two-way (group by trial) MANOVA showed a significant main effect of trial (Wilks' Lambda (48, 1582)=2.44, $p<.0001$). This effect was caused by a significant improvement in correct RTs (F (8.18, 270.08) =3.96, $p=.0002$) from 4295 ms on Trial 1 to 3319 ms on Trial 25. The MANOVA also revealed a main effect of group (Wilks' Lambda (4,64) =2.84, $p=.0312$), caused by differences in correct RT (F (2,33) =3.84, $p=.0318$). Group 1 had an average correct RT of 4062 ms; Group 2, of 3452 ms; and Group 3, of 2900 ms. Post hoc analyses (Hays, 1973) indicated that none of the pairwise comparisons were significant.

Separate resources groups (Groups 4, 5, and 6). The correct RT and percentage error of the running difference task were significantly correlated ($r=.73$, $p<.001$). The MANOVA indicated a main effect of trial (Wilks' Lambda (48,1582) =5.04, $p<.0001$). This effect was caused by improvements in both percentage error (F(24, 792)=2.47, $p=.0001$) and correct RT (F (7.56, 249.61)=7.01, $p<.0001$). The percentage error improved from 23.3% on Trial 1 to 16.1% on Trial 25. The corresponding change for correct RT was 5190 ms to 3306 ms. There was also a main effect of group (Wilks' Lambda (4,64)=4.14, $p=.0048$), reflecting between-group differences in percentage error (F (2,33)=5.27, $p=.0104$). The percentage error for Group 4 was 25.7%; for Group 5, 16.5%; and for Group 6, 15.5%. Again, post hoc analyses (Hays, 1973) revealed that none of the pairwise comparisons were significant.

The percentage error and correct RT for the matrix task were not significantly correlated. Therefore, two-way (group by trial) analyses of variance (ANOVAs) were performed on the dependent measures. The ANOVA performed on the percentage error showed no significant effects. The corresponding ANOVA performed on the correct RTs revealed an effect of trial (F (11.95, 394.36)=6.74, $p<.0001$), reflecting an improvement from 5602 ms on Trial 1 to 2938 ms on Trial 25.

Response strategies. The response strategy used during the fifth dual-task block was identified for each subject. If, on a given trial, 90% or more of the subject's responses to one task occurred within 100 ms of a response to the other task, the strategy for the trial was classified as simultaneous. If 90% or more of the responses to one task were followed by a response to the other and occurred more than 100 ms after a response to the first task, the strategy was classified as alternating. All other strategies were classified as massed (for a more detailed description, see Damos, Smist, & Bittner, 1983). The most frequently used strategy in the fifth block was identified as the

subject's strategy for that block. The results of this analysis are shown in Table 1.

The distribution of the shared and separate resources groups was compared by combining the distributions of Groups 1, 2, and 3 and the distributions of Groups 4, 5, and 6. A chi square test for independent samples (Siegel, 1956) was significant (chi squared (2)=18.35, $p<.001$), indicating a difference in the distribution of response strategies between the separate and shared resource groups. This effect appears to be due to between-group differences in the frequency of the simultaneous and alternating strategies.

As seen in Table 1,there was little difference in the frequency of strategy use among the shared resources groups (Groups 1, 2, and 3) and only a small difference in frequency among the separate resources groups (Groups 4, 5, and 6). The frequency distribution for the separate resources groups was examined using a chi square test for independent samples (Siegal, 1956) and was not significant.

Table 1

Distribution of response strategy by group

Group	Strategy		
	Massed	Simult.	Alternating
1	7*	4	1
2	8	3	1
3	8	4	0
4	7	0	5
5	6	0	6
6	11	0	1

* Entries represent the number of subjects using the strategy.

Discussion

This experiment appears to demonstrate that the amount of single-task practice has little, if any, effect on dual-task performance regardless of the amount of resource overlap. However, all of the conclusions concerning dual-task performance rest on the assumption that the amount of practice on a given task is directly related to performance on that task. Specifically, subjects in Groups 3 and 6 were supposed to approach asymptotic performance on each of their component tasks; pretest data indicated that subjects in those groups received enough practice on each task to approach asymptotic performance. Subjects in Group 2 were supposed to have poorer performance than those in Group 3 because Group 2 subjects received only half as much practice as Group 3 subjects. A similar assumption was made about the relative performance of Groups 5 and 6.

To test the assumption about asymptotic performance, performance on the trial immediately preceding dual-task practice was compared to that on the final trial, which immediately followed dual-task practice. Group 3 showed a decrease of 250 ms and 3% error on the running difference task between these two trials. Group 6 showed a decrease on the matrix task of 333 ms and 5% between these two trials. Thus, Group 3's performance on the running difference task and Group 6's performance on the matrix task did not approach asymptotic levels prior to dual-task practice.

To test the assumption about the relative performance of Groups 2 and 3, the performance on the last trial preceding dual-task practice for Group 2 was compared to the performance of Group 3 on the same number trial (e.g., Trial 8 versus Trial 8). The same relative comparisons were made for Group 5 versus Group 6. Group 2 had a lower percentage error on Trial 8 of the running difference task than Group 3 (12% versus 17%, respectively) and a smaller correct RT (1826 ms versus 2179 ms, respectively). Group 2 also had the same percentage error on Trial 6 of the alphabet task as Group 3 (3%). A similar examination of the performance of Groups 5 and 6 indicated that Group 5 had a lower percentage error on the running difference task on Trial 8 than Group 6 (6% versus 9%, respectively).

It appears, therefore, that the lack of between-group differences in dual-task performance was caused by the unsuccessful manipulation of the single-task practice variable. Both Groups 3 and 6 did not approach asymptotic performance on at least one task of their combination before performing under dual-task conditions. Group 2 performed as well or better than Group 3 on three of four dependent measures despite the fact that Group 2 received half as much practice as Group 3. Similarly, Group 5 performed better than Group 6 on one of the measures. Thus, no conclusions can be made about the effect of single-task practice on dual-task performance from this study.

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